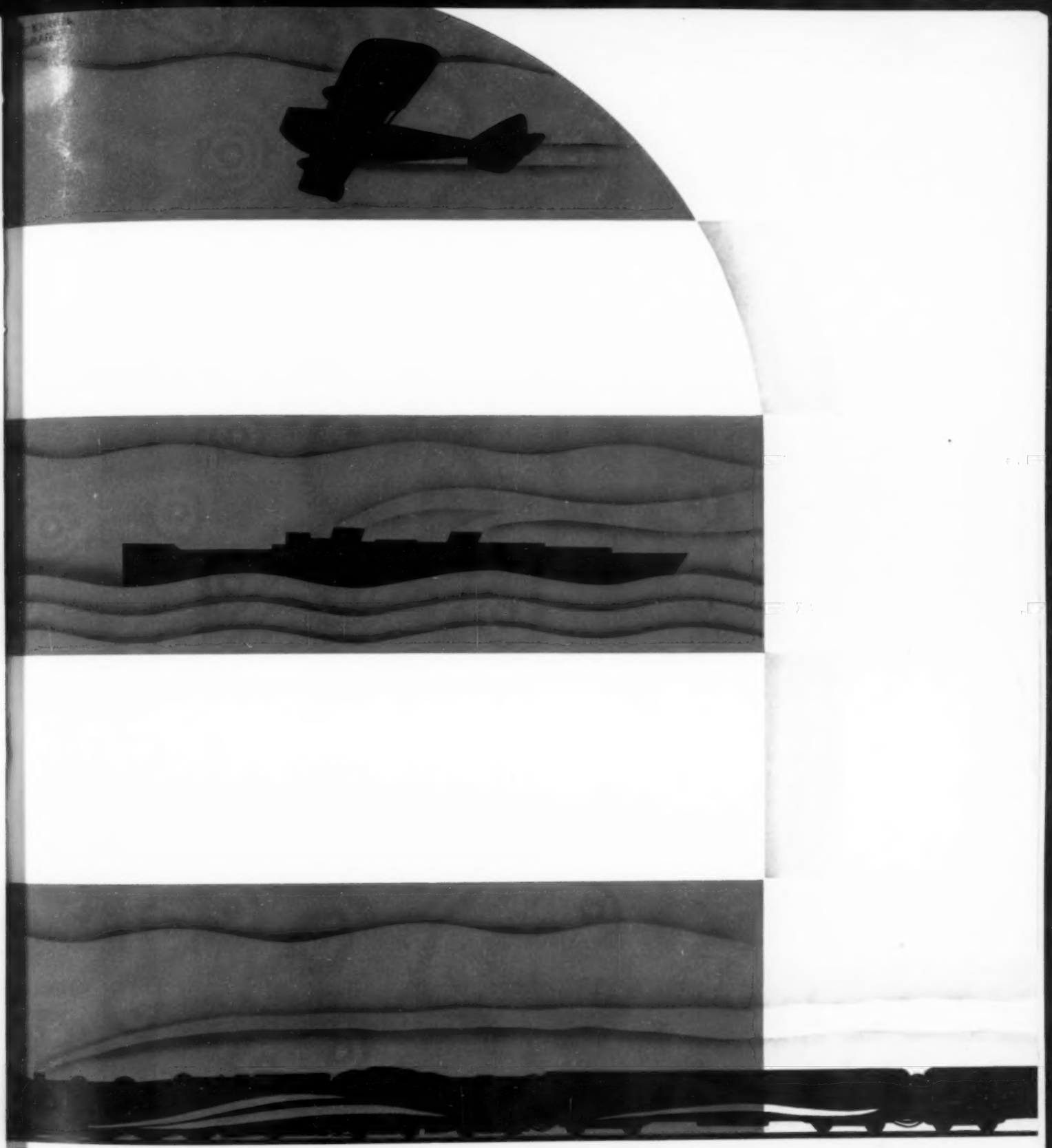
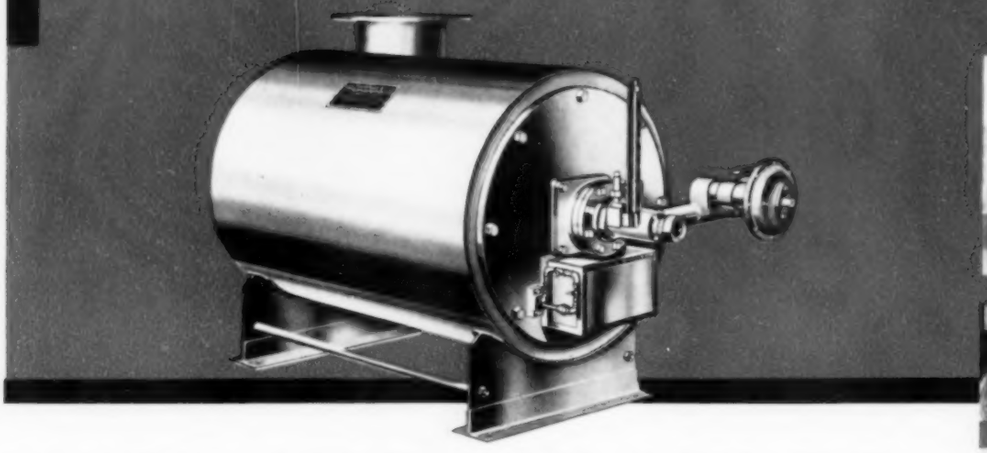
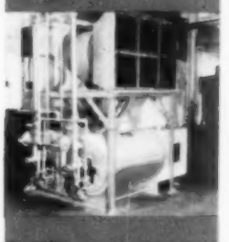


METAL PROGRESS

APRIL 1934

IN MANY INDUSTRIES





Reading from the top down, the installations illustrated show SC Air Heaters installed on Rust Proofing and Coating Oven; Baking Oven; Japanning Oven; Enameling Oven.

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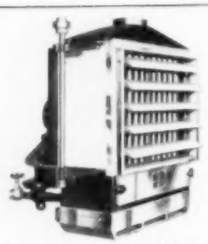

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TOLEDO, OHIO SALES AND ENGINEERING SERVICE IN PRINCIPAL CITIES

April, 1934
Vol. 25, No. 4

METAL PROGRESS

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Professor Waterhouse has good authority behind his article on page 32 about rails made of chromium alloy steel, for he was metallurgist and inspection engineer at Lackawanna Steel Co., (which operates one of the country's largest rail mills) for nearly 20 years. Since 1922 he has been at "Boston Tech", teaching about iron and steel, and consulting.

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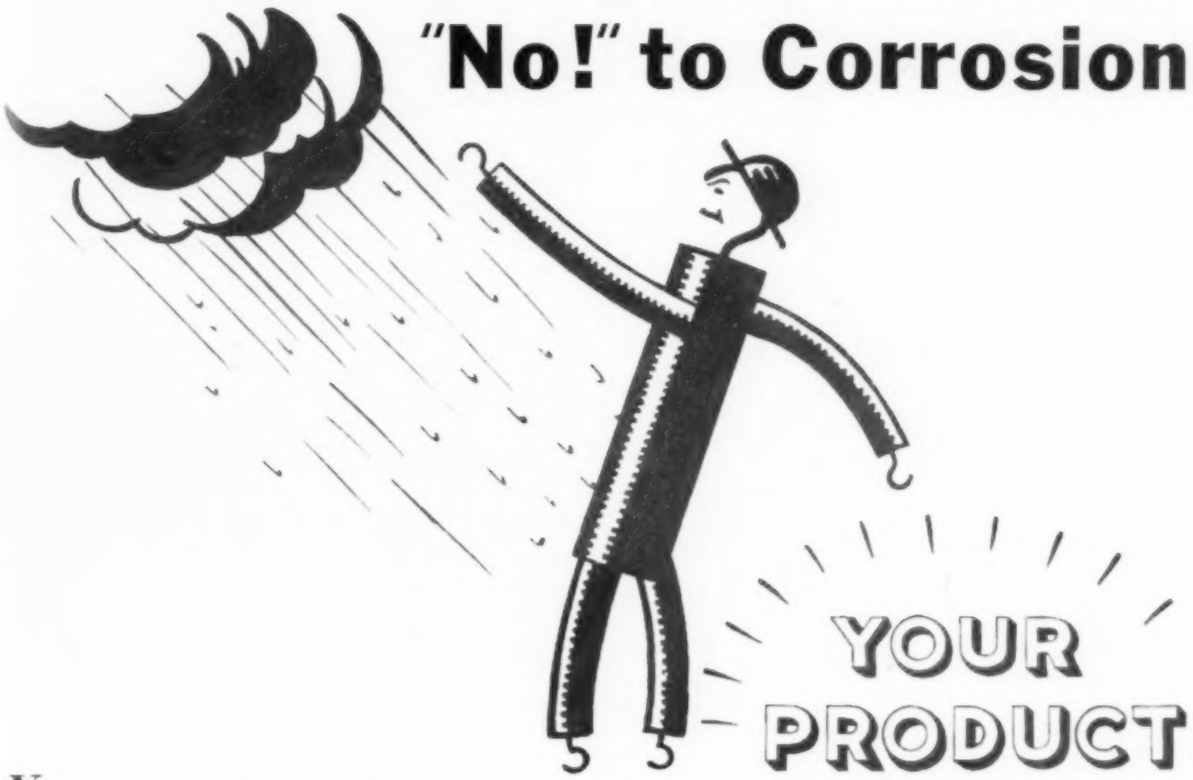

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Photo by H. Armstrong Roberts

SAFETY

A Signalman's View of the Passenger Situation

by the Editor

HIGH SPEED TRAVEL

requires new cars and engines

ON ONE STRETCH OF U. S. ROUTE 6, the newly built highway parallels a double track Class I railroad and the banks of an old barge canal. Alongside is the broad and placid Susquehanna, while overhead flies an occasional mail plane.

At one glance is seen the transportation problem of America. The river, the first highway into the backwoods, long unused, even though frequently improved by Uncle Sam as an inland waterway. Next is the canal bed, the "modern" transportation of a century ago, now grass grown. Then the railroad, the most powerful unifying force in these United States during the last 50 years. Is our railroad system, worth 30 billion dollars, to retrograde like the river and the canal, from failure to compete with motorized transport on highway and in air?

Since 1920 the passengers carried by railroads have decreased 40%! Almost all of the short haul business except commuters has gone to private automobile and to busses. "Oh, well," said the railroader, "that traffic never paid for itself anyway. We still have the profitable Pullman rider." But now even that business is being eaten into, as more and more long jumps are made by air.

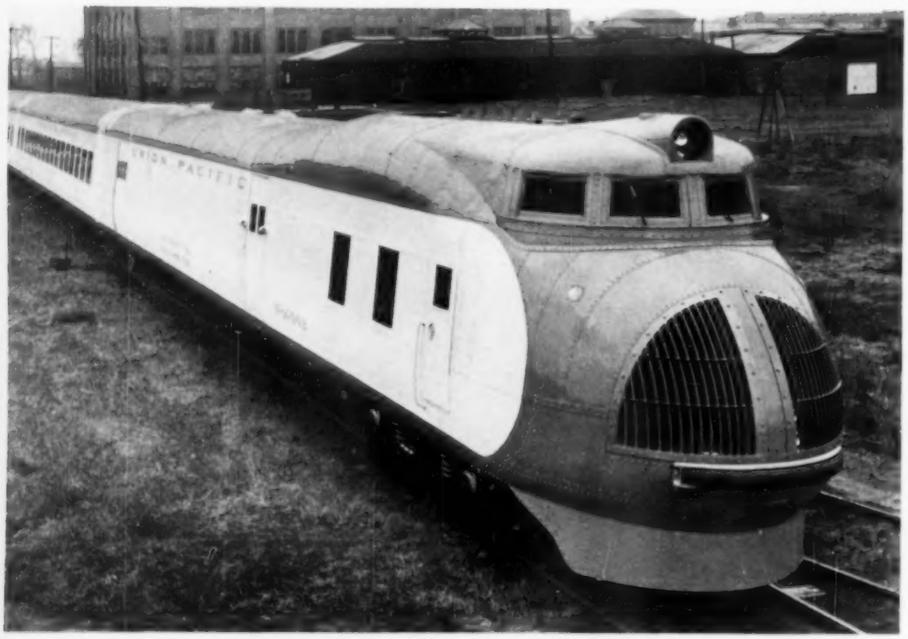
Up to 1929 his attitude toward motor trucks was similar, for they carried only about 2% of the nation's freight. What the figure is now can only be guessed, in view of the truck fleets delivering overnight from shipping platform to receiving shed anywhere up to 200 miles away.

Passenger traffic is the subject of the present article. Some railroad men think it is not worth regaining. Others have long been making a consistent effort to improve the equipment, air condition the trains, and better the schedules, so as to retain the old patronage for distant journeys, or for shorter trips in congested areas. The latest and most spectacular moves in this direction have been the development of high speed, stream-lined units of light weight, driven by gas engines or diesel-electrics. Their use is frankly experimental, for what combination of fare, speed, comfort, and convenience is necessary to woo the traveling American back to the rails is entirely unknown.

Efforts to Regain Traffic

Doubtless the optimum combination will be different in different regions. In the congested New York to Washington area, for instance, most attention is being given to frequent service, acme of comfort, and reasonably high speed from home to destination. Present schedules of steam-drawn express trains average 50 miles per hour — somewhat higher than in any other region. Electrification of the Pennsyl-

vania railroad will permit this speed to be doubled if necessary, even with the heavy passenger cars now existing. It is a fact not widely understood, however, that this $150,000,000 improvement was authorized at a time when freight traffic had all but overloaded the existing tracks, and it was believed cheaper to handle longer trains at higher speeds by electric locomotives than to lay additional rails. Likewise a fast regular run, Washington to New York, will quite probably apply to perishable freight before a 4½ hr. run will be printed in the passenger schedules.



Union Pacific Articulated Three-Car Train, Using Maximum Amount of Strong Aluminum Alloys. Exterior finished in golden brown and canary yellow lacquer. A 600-hp. gas-electric drive gives it 90 miles per hour cruising speed

The problem in the more sparsely settled west and southwest is quite different. There it is necessary to regain patronage rather than retain it. Likewise the distance between centers is much greater, and railroad fare at 3.6¢ per mile is an item. Existing express schedules are usually slower. For these reasons the operating officials of some railroads are staking their hopes on lower fares, but at least three others have bought light weight, air conditioned trains, for extremely fast service on long runs.

Most publicity has been given the $200,000 three-car unit built for Union Pacific system by the Pullman Car & Mfg. Corp. As seen from the photograph alongside, it is a radically different type of passenger equipment, streamlined for high speed, and expected to operate at a minimum of cost.

Maximum use of strong aluminum alloys has produced a three-car unit (112 passengers) weighing 85 tons, completely equipped — about the same as a single sleeping car. Motive power is furnished by a 600-hp. Winton V-12 gas engine, direct connected to a 425-kw. generator. Two 300-hp. traction motors are mounted on the axles of the front truck. With necessary auxiliaries this entire power plant weighs about 20 tons — 67 lb. per horsepower, only about one-third as much as required in a modern steam locomotive.

As long ago as 1923 passenger car builders began to save weight on rolling stock by using aluminum for doors, conduit, fittings, and interior sheathing, thus saving from 6 to 8% on the total. In this Union Pacific unit advantage has been taken of automobile body and aircraft fuselage design — that is, the entire frame of the car, including interior and exterior sheathing and floor plates, is riveted together as a tubular beam to take the stresses and impacts of starting, movement, and stopping. All interior details and equipment are refined — for instance the tea services weigh 189 lb. as compared to 530 lb. for the equivalent chinaware found in a dining car.

Light-weight trains obviously take less motive power. Streamlining also reduces wind resistance at high speeds. The shape of the front and rear ends of this unit was worked out during experiments in the wind tunnel at the University of Michigan; it is estimated that these end shapes (plus flush windows, doors, and vestibules, and completely shrouded trucks) save half the power required at 100 miles per hour were the cars of conventional shape.

So much for the elements which lend high speed. Comfort to passengers is another im-

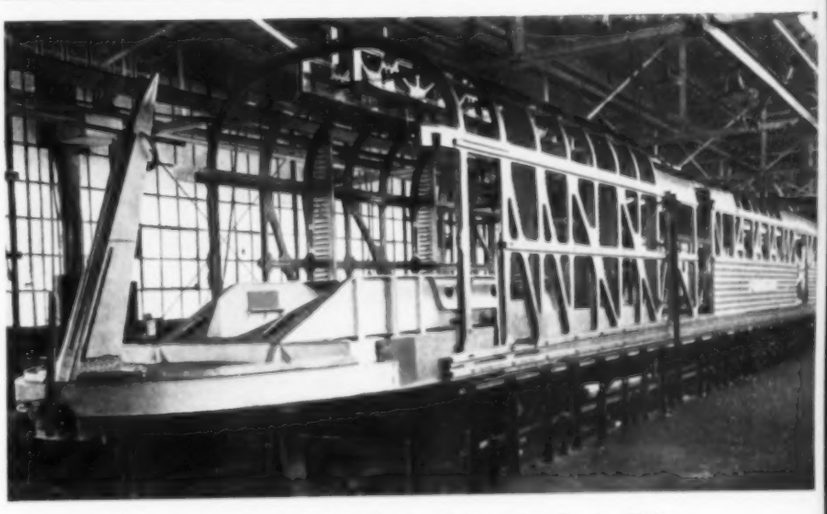
portant feature, provided by many luxury items. The power plant includes an air-conditioning unit which delivers washed air of proper temperature and humidity by underfloor duct to a register at each seat; exhaust vents are in the ceiling. Air pressure is slightly above outside, so there is no infiltration of dust around window and door frames. Roll is reduced by a low center of gravity: 38 in. from the rails, instead of 58 in. commonly found in standard steel cars. Much consideration was given to pneumatic tires, but their reliability at high speeds was questioned, so conventional rolled steel wheels are being used.

Speed and comfort are useless unless safety is guaranteed, and this new train has various interlocking safety devices and automatic signals which attract the notice of railroaders. Fuel is a petroleum distillate with low flash point (described as "non-explosive") contained in tanks under the engine room floor, and pumped through special carburetors in a thin stream only as required.

While the above description has done no more than mention the most interesting innovations in this railroad unit, it is obvious that a surprisingly great use has been made of the best modern metals and alloys. Aside from the frame and sheathing, the roller bearings, the gas engine with its welded frame and cylinder jackets, the electrical equipment, the air conditioner and the many automatic controls all require materials and fabricating processes somewhat strange to the old-time railroader.

Light weight combined with adequate strength is also possible with the use of stainless steel, properly welded. No allowance for corrosion need be made; neither is any extra metal necessary to take care of joints less than 100% efficient, if the parts are properly welded together. Consequently only the net amount of metal required at positions of maximum stress needs to be provided. The gross weight (in comparison with ordinary mild structural steel of 18,000 lb. per sq.in. ultimate tensile strength) is further reduced, owing to the ability to strengthen the austenitic 18% chromium 8% nickel alloy to 180,000 lb. per sq.in. by a moderate amount of cold rolling, with the retention of considerable ductility, as indicated by an elongation of 12% in 2 in.

These ideas, first worked out by aeronautical engineers, have been promoted for some time by the Edward G. Budd Mfg. Co. of Philadelphia in connection with its patented process of "shot welding" — an extremely rapid method of spot welding described in METAL PROGRESS last July. (The current-time-pressure relationship is closely controlled, so the heat of welding softens and changes the microstructure at the faying surfaces in a region so restricted that the outside of a 0.010-in. sheet is unaffected.) The first application for railroad traffic was made early in 1932 in the form of a 40-passenger suburban motor car for the Reading Railroad. Next came a two-car unit for the Texas and Pacific Railroad, delivered since New Year's. A three-car unit for the Burlington system is under construction.



Framing of Power Plant Car of Burlington Three-Car Train, Using Maximum Amount of Stainless Steel. Note heavy front end construction, motor foundation and box girder effect of entire skeleton. Some external sheathing is attached at the far end

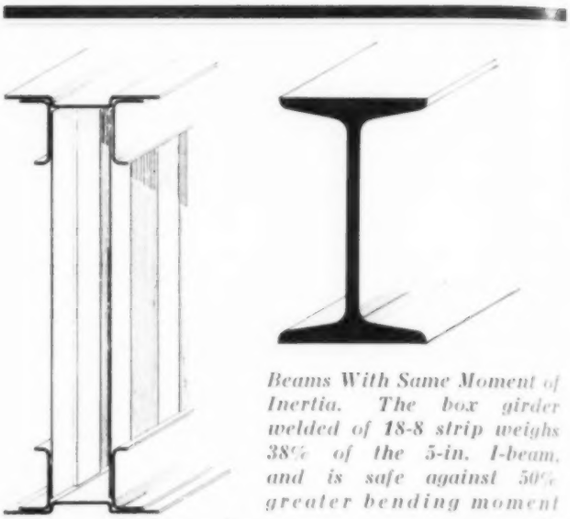
While these units have details which differ in numerous respects, the method of achieving lightness in the structure, together with strength and rigidity, is the same, and is important enough for a brief discussion. It hinges on the ability, by welding, to build up structural shapes which utilize the metal in a much more efficient way than a rolled beam, for instance.

Compare a 5-in. I-beam of structural steel

with a built-up girder of cold-worked 18-8; comparative cross-sections are shown in the sketch. The moment of inertia of the two is the same (12.1), but the sectional area is 2.87 sq.in. for structural steel, resulting in a weight of 10.0 lb. per running foot, whereas the area of the 18-8 beam is 1.08 sq.in., and the corresponding weight only 3.8 lb. The safe bending moment carried by the structural steel is 87,000 in-lb., whereas the 18-8 beam is safe against 130,000 in-lb. (factor of safety of 4). The web thickness of the I-beam is ¼ in., but in some places 18-8 load-carrying members are no more than 0.012 in. thick. Even this need not be protected by paint, so the designer has the utmost freedom in using closed or box sections in inaccessible places. The modulus of elasticity of 18-8 is the same as carbon steel, so excessive deflections under given loads are not a problem.

By proper design and use of cold-worked 18-8, shot welded into a homogeneous structure, the Budd Co. finds that the weight of one of these new passenger cars of the day-coach type is 730 lb. per passenger, as compared with 1620 lb. per passenger in the present standard equipment. Parlor car construction is heavier, weighing 1300 lb. per passenger, but even this is much lighter than a steel Pullman, which weighs 4200 lb. per passenger.

Comparative cost figures are about as follows: An eight-car express train with steam locomotive (capacity of 380 passengers) weighs 1,630,000 lb. and costs about $365,000, which figures to 22¢ a pound or $960 per passenger. A diesel-electric train made of 18-8, carrying 236 passengers, weighs 230,000 lb. complete and costs $300,000. This is $1.30 a pound or $1270 per passenger. Estimated operating costs at 70 miles per hour are, however, $1.60 for the steam train, and 60¢ for the diesel-electric. Those mathematically minded can figure in the interest on the investment and compute the number of passengers which must be carried before the railroad breaks even on the operation. The balance appears to be on the right side, for, as remarked at the outset, the Texas and Pacific railroad already has a two-car unit operating between Fort Worth and Texarkana, a 500-mile round trip on a 10-hr. schedule, about half the time of steam trains. The Burlington has also ordered a three-car unit.



Beams With Same Moment of Inertia. The box girder welded of 18-8 strip weighs 38% of the 5-in. I-beam, and is safe against 50% greater bending moment

Conservative railroad men are apt to compare these very light aluminum and stainless cars to the fragile wooden cars of earlier days, and even have dubbed them "tin trains." "What will happen to them in a wreck? Will they fold up like a crashed airplane, or be demolished in a grade crossing accident?" This is, of course, a very pertinent question; it can be stated immediately that the cars are built to M.C.B. specifications and are in no respect a fragile construction.

It is well known that the energy due to motion of a body is proportional to its mass and the square of its velocity; the potential damage to the car body from a derailment of a 20-ton passenger car at 90 miles per hour is no more than to its 80-ton counterpart traveling at 45 miles per hour. Structurally, then, if the strength and rigidity of the aluminum or 18-8 car is made equal to the standard steel construction (which has been proven by experience to be safe), there should be little fear of excessive damage from an ordinary mishap.

Naturally the railroad man's first effort is to avoid accidents rather than construct damage-proof rolling stock. Hence the high speed trains have the latest improvements in air brakes, and a multiplicity of safety devices. The light cars can also be stopped very quickly — likewise the motor-man is placed in a position where he has best visibility, both sides of the track. The matter of rapid acceleration and deceleration is of great importance to both

economy of operation and safety. These facts are not hypothetical, they have been proven by European experience with such a train as the "Flying Hamburger," which cuts the regular schdule in half.

Some data on the units already designed may be interesting. The Reading car has a skeleton made largely of 0.030-in strip and is sheathed in 0.010-in. metal. The trucks are of riveted carbon steel, each having six disk wheels carrying 30x3-in. tires inflated to 85 lb. An inner rim prevents the flanges from riding fishplates if the tire is flat. Springs are of rubber, compression type. Brakes are of expanding automotive type, and can stop the car from 60 miles per hour in 400 ft. This car has a diesel-electric drive, with Cummins six-cylinder engine.

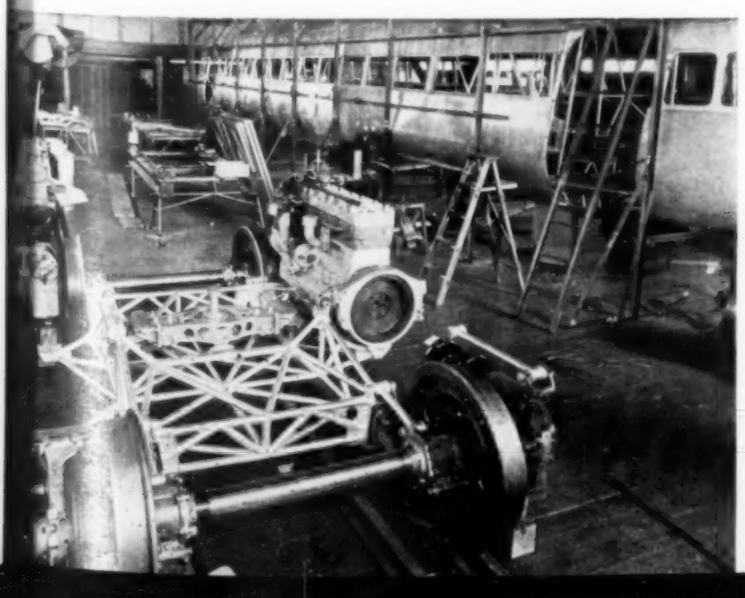
The Texas and Pacific unit consists of an engine-baggage-mail car, riding on eight steel-tired wheels, and an air-conditioned 76-passenger car riding on 16 pneumatic tires. Trucks are largely of cast steel. Two 240-hp. American La France gasoline engines are direct coupled to generators at the front end of the car (and for repairs can be rolled directly forward out of the car, through wide open doors.) A high speed driving motor is geared to each of the four axles under this car. Top speed is 80 miles per hour. In both generator and motor the maximum amount of aluminum and self-ventilation is utilized to reduce the weight to 13 lb. per kw. and 11 lb. per hp. respectively.

The Burlington unit is to negotiate somewhat greater distances; it has two passenger-carrying trailers instead of one, and a compartment for buffet service. The power plant is a 600-hp. straight-eight diesel engine (Winton) and generator-motor equipment capable of 120 miles per hour speed. Units are articulated at ends (ride on common trucks) like the Union Pacific unit, and present no irregularities in outer contour at the vestibules.

Space permits nothing more than mention of many interesting attempts to provide more adequate transportation on lines whose traffic has been all but lost to busses. Experience indicates that substitution of a motor car instead of a steam train, operating on the old schedules, will not recover traffic, even though it cuts the cost per car-mile. Hence the recent proposals (like the "rail-bus" — its name sufficiently indicates its appearance and construction — of the Four Wheel Drive Auto Co., and the Clark "Autotrain," a luxurious limousine riding the rails) adapt conventional automobile engines and drives, and have acceleration and running speeds comparable with their highway counterparts. Wheels have a thick layer of rubber vulcanized securely inside the steel tire (standard of Master Car Builders) and then pressed onto steel or aluminum centers. Roller bearings are, of course, provided throughout, in all this high speed rolling stock.

Because of its interesting use of welded chromium-molybdenum steel tubing for a structural skeleton, the Pullman "Railplane" built by the Stout Engineering Laboratories warrants some space. The illustration alongside shows how this method of framing, now practically standard for aircraft fuselages, has been used even in the trucks, in combination with some high strength steel castings. Roadway shocks and noise are insulated from the car body not only by the rubber rings in the wheels, but by the use of rubber bearing pads at axle journals, spring seats, and king pin. Power to drive the car at 60 miles normal speed (90 maximum) is had from two 6-cylinder Waukesha gas engines, each capable of developing 160 hp. The accompanying view shows how they are mounted outside

Pullman "Railplane" Uses Oxwelded Chromium-Molybdenum Tubing for Trucks and Main Frame. Gas engines, mounted on either side of leading truck, drive through worm gear. Car body, partly constructed, is shown at rear; note skeleton of tubing and outer metal sheathing adapted from the standard design of aircraft



the wheels; they are housed in a pocket inside the car sheathing, and thus are shrouded so as to offer little wind resistance. Liberal use of alloy steels in engine and drive, following conventional automotive practice, is a matter of course. An automatic drive avoids any gear shifting.

In the design of this car the first requirement was adequate strength and torsional rigidity; next the weight was reduced to a minimum and with low center of gravity to avoid the rolling of interurban cars; full streamlining gives high speed with moderate power. As a result this 50-passenger unit weighs but 12½ tons complete.

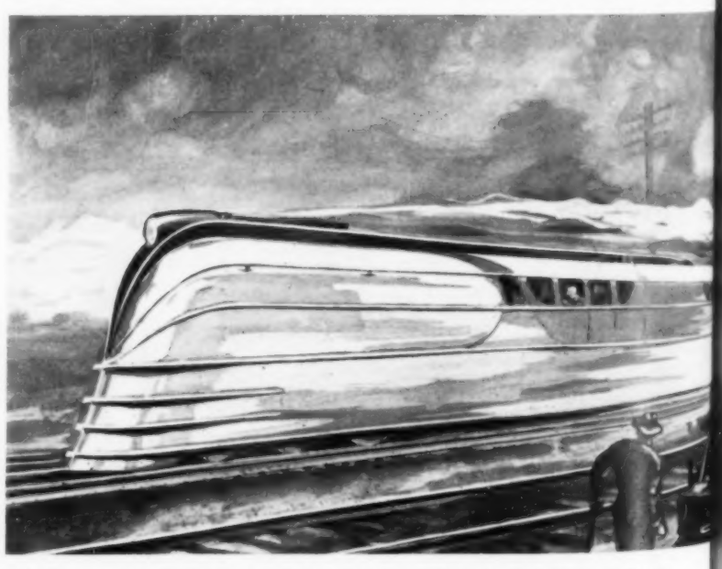
It will be observed that the above ideas and achievements toward high rail speeds use some motive power other than the tried and true steam engine. Whether the expected economy from diesel or gas-electric units will actually accrue will depend upon whether these complicated engines can be built rugged enough to operate for several thousand hours without general repairs. Two large and amply proven advantages of the steam engine, with hardly one-quarter as many moving parts, are the reliability and low maintenance cost.

Special runs have been made frequently enough in the last half century to indicate that there is no reason why steam engines cannot provide any speed which the rails, road bed, and bridges will endure. The American Locomotive Co., for instance, has already designed several locomotives capable of running 120 miles an hour, in which are incorporated all the advances in engineering brought forward in the last 15 years. In order to reduce wind resistance and improve appearance, Otto Kuhler (an engineer-artist whose work is known to readers of METAL PROGRESS by his fine etchings) has been retained. One of the designs is shown in an accompanying view.

Trend in modern engines has been more and more toward clean outlines of the boiler, with stack, steam dome, and sand box suppressed. A more complete shrouding molds the front end, covers the running gear, and joins up with the tender. In Mr. Kuhler's design the fender has stout rails for anti-climbers; all top auxiliaries are in a cowling behind the headlight and the cab is streamlined to full width of the train. Service openings and demountable sections give access to the machinery.

It is contended that if light-weight trains, such as those cars exhibited at the Century of Progress, are coupled to light-weight locomotives into a single streamlined train, the resulting rapid and reliable schedules will be all that can be desired. Change from old equipment can be made with the present crews and terminal and shop equipment, and after such improvements to the right of way as would be necessary to provide safety and comfortable riding to any high speed unit. These ideas are being tested experimentally by at least one of the important Eastern railroads with two complete trains, one passenger, one freight, reconditioned for 80-mile speeds.

Whether or not the ultimate result will be achieved with electricity, gas, or steam (a combination will doubtless rule for many years to come) the drive toward high speed transportation of railroad passengers will mean much new equipment, engineered in the light of the automotive and aircraft developments, and utilizing large quantities of quality metals.



High Speed Steam Engine, Streamlined with Duralumin or Stainless, Designed by American Locomotive Co., Modeled by Kuhler

by Frederick H. Williams
Assistant Test Engineer
Canadian National Railways
Montreal

MODERN LOCOMOTIVES

seldom fail from poor metal

MOTIVE POWER IS OF PERENNIAL INterest to railroad men. Some regard it as a matter of course; others never quite get over the thrill of a powerful, vibrant locomotive. In this they are like the two men who were looking at Niagara Falls for the first time; one was awed by the grandeur of the scene, the natural beauty and tremendous power — thrilled and humbled. The other could not see that there was anything so wonderful in a stream of water falling over some stones! Every railroad man is either one or the other in his view of motive power. Personally I believe there is more to it than mere "water falling over some stones."

Some of the questions most frequently asked by our friends in the mechanical industries, sometimes with an air of slight superiority, are "Why do locomotive builders stick so close to common iron and low carbon steel? Why are not some of these massive parts replaced with special alloys? Why don't you take some weight off your wheels?" I will attempt to answer them.

First, we must continually bear in mind that the most perfect steel ever produced will not *of itself* give us ideal results when applied to railroad rolling stock, engines particularly. In other words the treatment and mistreatment it gets in shop and service is the ruling consideration. Second, the full value of ordinary steels has frequently not been obtained when the railroad man has rushed to the more expensive special steels, only to find himself in no way better off — often worse. This is not fancy, it is fact! Any study of the cause of failure of the ordinary steels will emphasize the belief that (under like conditions) special steels would have failed as readily.

Corrosion plays a leading role in service failures if it is not properly understood and carefully eliminated as far as humanly possible. Heat treatment, chemical content, and mechanical work all have their hand in upsetting or aiding the perfect and efficient service each grade of steel has in itself. Machine work improperly done is a star actor in ruining the best intentions of man in meeting the requirements of the locomotive.

One has but to look at the fracture of a 12-in. axle to realize the power of little things. A progressive crack, traced in clear diminishing waves to its source, shows that a tool mark 0.01 to 0.02 in. deep has caused its downfall. This, also, is not fancy; it is fact. Perhaps if a census were taken of failures, a greater percentage of the whole would be found to be caused by tool marks. This applies to ordinary

as well as special steels. Think of this and then think of the fact that a tool mark 1/64 in. deep on a main driving axle may cost a railway a quarter of a million dollars.

When one first starts the study of failures, the tendency is to expect the microstructure to give a clue to the problem of why this or that failure occurred. One soon finds out that wonderful as the microscope is, useful as it was, is, and will be, the first approach to the subject must be from the more prosaic angles of machine shop practice and the service the part was called upon to meet.

It cannot be too emphatically stated that a *proper* conception of proper machining is necessary to the satisfactory functioning of ordinary steels, special steels, and even of superlative steels. One must be fully conversant with the uses of the parts and the stresses they have to withstand, and also fully aware that rough machine work should not be tolerated where reverse stresses are prevalent, and that fine machine work is wasted where no stresses come and the appearance is not important.

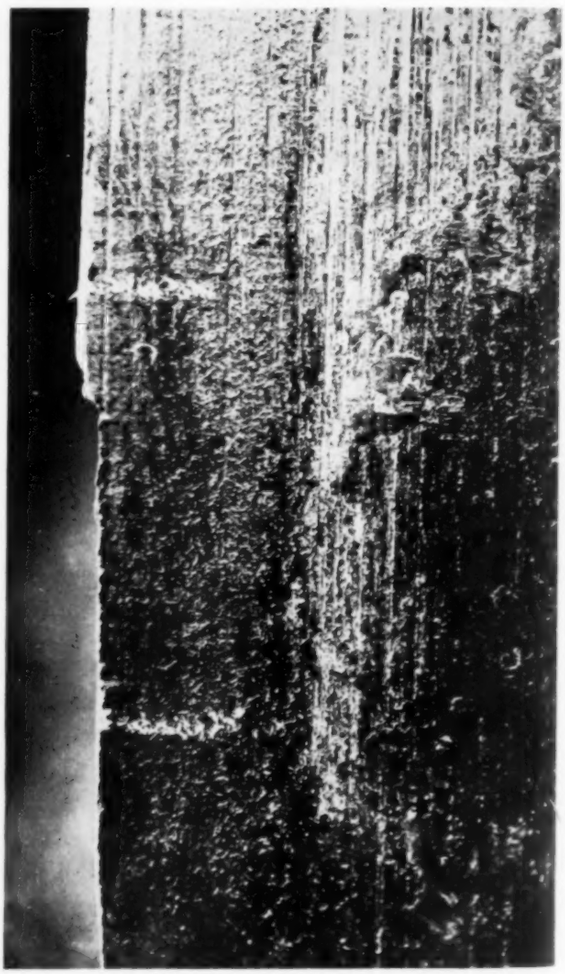
Damage by Careless Machinists

A coarsely turned fillet is an invitation to failure, regardless of the steel used. A scored or cold worked surface in a fillet means ultimate failure, be the steel plain carbon or the finest alloy, when the working stresses, concentrated at the scratch, are more than the endurance limit of the metal.

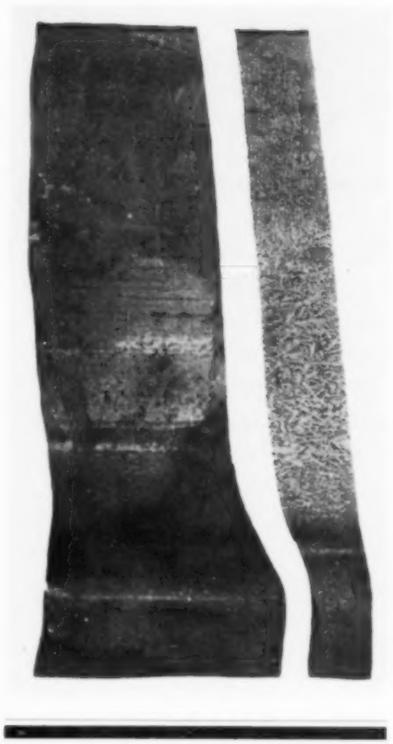
It is a debatable question as to what "fatigue of metal" consists of, and even whether the name is correct. Regardless of those questions, it has been amply established that the endurance limit of a steel under alternating stresses has a real value much less than the tensile strength. This value may be expressed in pounds per square inch, and is as dependable as any of the other mechanical properties. Its value has been determined experimentally for all of the common steels and alloys. But these determinations are useless, and worse, if they are depended upon for their full value in parts where the value is shattered by tool marks, score marks, corrosion from many substances, or cold worked surfaces.

The railroad man often does not clearly realize just what corrosion does to his work. True, he may have an idea of the wastage resulting from heavy rust, but he does not understand that many failures of parts in service are due to corrosion. When he tries to overcome these failures by using a special steel he may be greatly surprised to find them still occurring. He is merely verifying in a practical way the laboratory finding that the endurance limit of a heat treated or alloy steel is no higher than an annealed carbon steel if both are tested in mildly corrosive surroundings.

Failures due to stress-corrosion and to pres-



Tool Marks on Wheel Fit of Fractured 12-In. Axle. Two chalk marks locate start of fatigue cracks on tool marks. Tool marks are somewhat indistinct in bands; these bands are due to pressure-strain corrosion, and give the appearance of the axle "bleeding" at the line of contact with wheel center



Fragments of Steel Tire, Unetched at Left, Etched at Right. A roughly turned tread contains a series of hills and valleys. Brake shoes heat the hills and the hot metal is cooled by metal underneath, so hills are chilled and crack. As many as 35 cracks three-eighths of an inch deep have been found in one tire

sure-stress-corrosion are very common and varied and occur in strange places. Boiler plates, boiler tubes, firebox sheets, piston rods, axles, crank pins, staybolts, all fail through this insidious, creeping, penetrating action. Much has been written about its characteristics, if not completely on its occurrence.

For instance, a piston rod fails near the crosshead fit, just where the fit is tight; at first glance it seems to be a clear case of "fatigue," but one finds upon closer examination a strangeness of the direction in which the crack penetrated the surface. The clearly written papers by D. J. McAdam, Jr., and others give us the clue: Fatigue certainly, but stress-corrosion to start with; perhaps pressure-stress-corrosion or "bleeding" (which gives a dark, sometimes bloody appearance to the surface of the axle or crank pin for as much as 4 in. width of surface).

These causes may not require special steels to cure them, but special attention to mechanical, physical, or chemical changes to remedy a condition that would be similar and lead to similar trouble even with a special steel.

Now-a-days, when one mentions special steels, it is alloy steels and not plain carbon steels that come to mind. Before going to these alloy steels to meet special requirements, the engineer should halt and consider the question "Have I used the carbon steel to the limit which it can be used? Have I taken advantage of its excellent qualities to the fullest extent?" He may find that he has not, yet the value of utilizing plain carbon steel to the fullest is untold.

How many railroads have oil quenched and drawn their carbon steel axles or crank pins? How many have heat treated their carbon steel tires? Not all, I am sure. (While we can hardly call axles and tires "special" steels, they deserve special *treatment.)*

Possibly in times to come, special steel will be so advantageous that carbon steel of itself will be cast aside. So, perhaps, in the more distant future, what we now call "special steel" in its turn will go into the discard; our common carbon steels of today were once quite special.

A word or two on plain carbon steels for axles — those 12-in. ones bored 4 in. end to end that to the eye seem all too large. Even in this size and design the plain annealed carbon steel axle is too weak for the work required by heavier loads and higher speeds. It is asked "What do we think of quenched and drawn carbon steel axles to replace plain annealed carbon steel axles (as well as alloy steel axles of premature birth)?" We believe such a substitution will be most satisfactory. Experience to date with oil quenched and drawn carbon steel axles is beyond expectations; certainly a special steel for axles is not yet required. Its use is pushed further and further into the realm of the future.

Heat Treated Axles

It is well to note the reason for this move toward a heavy heat treated part which might be considered rash. Quenched steel axles are not accepted as practical things by some railroad men, but they find themselves on the horns of a dilemma. In developing heavy power, the locomotive designer specified hard bronze for journal bearings and overlooked the contact surface of the annealed steel axles and crank pins, with the result that things were not as pleasant as desired. Quenched and drawn axles give the desired bearing qualities and also add strength and fatigue resistance — all most

necessary. The results are that axle failures are reduced practically to nil.

Consider also springs: Numerous plain carbon spring failures put in an appearance as the power gets heavier and faster. Again special steels are strongly recommended, and again we urge sticking to carbon steel. All that is necessary is to change the treatment; the improvement is spectacular, for failures are reduced to a mere fraction of the old time record. Perhaps this can be made clearer by stating that formerly the spring steel leaf was formed, quenched and drawn with one heat. Today the spring leaf is heated to form, allowed to cool, reheated to quench, and again reheated to draw. All these operations are carried out at proper temperature and times. Similar improvement is noted in coil springs — the view on page 27 shows what happens to such a spring improperly fabricated. It is very questionable whether a fine alloy steel would have fared any better under similar mistreatment.

Locomotive designers favor the more conventional time-tested materials for reasons discussed in this article. Mr. Williams writes from a very extensive experience with locomotives built for 100-mile top speed and a 75-mile cruising speed; their regular schedule calls for runs of 333 miles in six hours, including stops

There is no doubt in my mind that special steels will eventually be used for springs to greater advantage than plain carbon steel, but it is well to remember that the special steel requires special attention, and only by careful handling can any improvement be made. There are great possibilities in alloy steels, but all should be carefully studied and tested in service before the good old reliable carbon steel is discarded. It is a cheap, easily handled steel of good serviceable characteristics.

Recent studies of grain size by the McQuaid-Ehn test open up new possibilities for carbon steel and give such new life to this old material as may astonish its friends. Not that it gives us new creations, but that it opens up new lines of thought and explains happenings that were unexplainable heretofore. For instance, it is my opinion that an axle of coarse-grained steel (after the McQuaid-Ehn test) will have a greater tendency to crack from overheated journals than one having a fine grain.

While emphasizing the thought that the most has not yet been got out of common steel, one should not forget cast iron. Cast iron has frequently been called a material rapidly becoming obsolete as regards locomotive construction. It is not by any means obsolete; it is coming into its own more than ever, owing to changes in physical characteristics that are usually brought about by the addition of alloys.

Some years ago, when asked to give an opinion on cast steel for cylinders on an order of 20 of the large, heavy locomotives, and having studied the subject and collected data on the use of nickel in cast iron for years, the following recommendation was given: "That the cylinders be made of nickel cast iron." The application of cast steel cylinders was being pushed at the time, since ordinary cast iron was not considered up to the requirements of the service. My recommendation was adopted and the Canadian National Railways became pioneers in the use of nickel cast iron locomotive cylinders on a large scale; we have never regretted the steps taken.

Nickel cast iron has many advantages and good points — comfortable, satisfying points — and one must include it in any consideration of special metals fit for locomotive construction. One can also include other alloy irons as well in this category, some not used as much, but worthy of consideration.

High Strength Castings

Cast iron of 50 to 60,000 lb. per sq.in. tensile strength is worthy of note. Cast iron free from porosity (other than its characteristic graphite areas), cast iron remarkably uniform throughout, is not to be despised. Therefore, railroad men and designers generally should consider alloy cast iron as a special material of great usefulness, worthy of thoughtful consideration, not only in cylinders but in many other parts where the tendency was formerly toward the special steels.

So much has been said about the hidden

excellences of carbon steel and common iron that the reader may assume that alloy steels have not been put into locomotives. As a matter of fact, alloy steels will have a great place in the development of tomorrow's locomotive. In fact they have even now, only I wish to warn against the indulgence of special steels before they have really been tried out in service.

Engine frames are being made extensively of alloy steels such as nickel steel and vanadium steel, even though carbon steels are quite common in the large and heavy locomotives. Nickel steel is being used in wheel centers, crossheads, and other castings, giving an added strength and toughness to the part that is not adequately furnished by plain carbon steel. Side rods have been made of nickel steel, vanadium steel, and other alloys which have given excellent service at reduced weight and increased strength.

Alloy or special steels are also being used in boiler and firebox construction, as the steam pressures are boosted higher and higher. Staybolts made of steel with a small percentage of nickel have proved the advantage of special steel for special purposes.

Definite and clear lines should be established. It is dangerous to use several kinds of steel on one particular shape, for they all look alike to the repair man — he cannot be expected to distinguish between a carbon steel and a nickel steel forging. In case it is necessary to heat treat in a repair shop, as after a straightening operation, an error on his part may involve an expensive failure.

To give in detail the uses and varieties of special steels, their characteristics and analyses would involve too extensive an article.

Weldability Important

In the use of special steels as well as plain carbon steel, one must not neglect to consider the necessary welding processes, both oxy-acetylene and electric, and the cutting operation by the oxy-acetylene torch. Alloy or special steels frequently do not react favorably to the heat inseparable from these operations, and this fact again favors the use of carbon steel.

Welding, cutting, or building up of locomotive parts made of special steels, if the proper and subsequent annealing or heat treating is neglected, ends disastrously for both railway and welding equipment manufacturer. This point is proven without doubt, as metallurgy has made such strides that rarely, if ever, can a failure lack evidence of its cause. The "perfect" repair is not without some clue indicating its presence!

Welding and cutting is frequently done without dismantling and in very restricted quarters. In some such cases careless and dishonest work has resulted in bad accidents.

One final word: It is hoped that these remarks and illustrations, which apply so frequently to failures, may not lead to a distorted view of the situation existing in motive power departments. Failures in metal are the rare exception rather than the rule. It is the railroad man's job to make them even rarer. But more information can be had from one failure than a dozen successes — hence their importance to designers, metallurgists, and inspectors, and their preponderance in such an article as this.

Fractured Coil Spring of Carbon Steel. Bar was scored in rolling mill, and such marks are frequent causes of failure. This spring was oil quenched from the mandrel and then pulled out before cold to be tempered by its own heat; about two-thirds of the cross section of the coil had a martensitic structure

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BETTER GAS ENGINES

automobile, aircraft, diesel

TRENDS IN THE DEVELOPMENT OF ALL internal combustion engines continue to be in the direction of increased power and efficiency. In each field there are also intensive efforts to better the adaptability of the power plant to the particular service for which it is intended.

Thus, designers of pleasure car and bus engines strive for flexibility, smoothness and quietness of operation, while aircraft designers have necessarily emphasized reliability and low specific weight above everything else, little attention having been paid, until very recently, to such items as smoothness of operation or reduction of noise.

The trend is also toward higher diesel engine speeds, resulting in greater power output for an engine of given size.

The remarkable advances in these machines are a result, first of improvements in fuels, and second of improvements in design and better selection of the materials used in engine construction. New alloys with new combinations of properties have been developed as well as methods of fabricating these alloys, so that the engine designer now has available, as never before, materials with properties not only particularly adapted to function in each engine part, but which are fabricated in a form allowing full advantage to be taken of them.

I shall try to sketch briefly the part which the various aluminum alloys are playing in these developments and why it is that their use has been found justified.

Changes in Automobiles

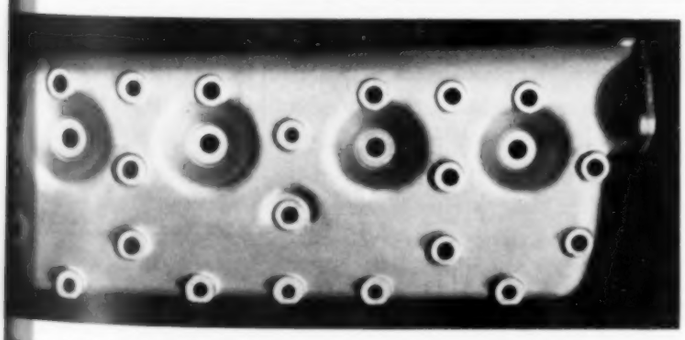
The extent to which any material is used in industry depends upon how such use affects the utility and cost of the product in question. These two factors, utility and cost, are being constantly balanced one against the other, with the consumer as the final judge. If two materials are equal from the standpoint of utility, the cheaper one will displace the more expensive. If they are unequal and the one of greater utility is higher in cost, as is usually the case, the question becomes one of balancing the added expense against the improvement in quality. There is probably no more striking example of the operation of this principle than the history of aluminum in the automotive industry.

Fifteen years ago about 40 or 50 million pounds of aluminum alloys were consumed yearly in automobile engine crankcases, oil pans, transmission cases and covers, while many

additional millions went into various body parts in the form of sheet and castings. Today only a very small fraction of this tonnage is used for such parts, for the reason that the American public has not been willing to pay the price for saving dead weight in their automobiles — the purchaser has preferred a somewhat lower first cost, accepting the higher operating cost which goes with greater weight.

On the other hand, he insists on brilliance of performance, smoothness, quietness, and flexibility of operation together with freedom from frequent carbon cleaning, valve grinding, and minor repairs. The result has been that while the "dead weight" applications have been largely lost to aluminum, it is being used in ever increasing quantities in places where it contributes directly to increased engine efficiency and performance.

Aluminum pistons and more recently cylinder heads have been adopted by car manufacturers in all price classes. The piston, because of its light weight, reduces loads on wrist pin and connecting rod bearings and minimizes engine vibration; its high thermal conductivity results in lower piston-head temperatures required for higher compression ratios and freedom from excessive carbon deposits. Continuous study has been devoted to this part — its design, method of manufacture and the proper alloy. The photograph shows the latest development, adopted by leading motor car manufacturers, known as the "T-slot" piston. It is very light, can be fitted with extremely close clearances and has a longer service life than any of its predecessors.



Water Jacketed Cylinder Head. Cast against metal top and bottom plates. Metal core pins give dense structure at all holes. High conductivity of aluminum prevents hot spots below internal ribs and bosses, and thus the motor can operate at higher compression

Light Pistons, Cast in Permanent Mold, Have Been Installed in Millions of Motor Cars. Intensive study of mechanical design has been a great factor in their success. In order to pass inspection for aircraft engines, forged aluminum alloy pistons are required

The aluminum cylinder head is the complement of the piston. Its use affords a combustion space, the exposed area of which is 85% or more of a high conductivity aluminum alloy, allowing further increases in compression ratio and thus making the same sized engine capable of producing 12 to 15% more power with a fuel saving of approximately 10%. Advanced methods of manufacture have done much to make this a possibility. The head illustrated is cast in a split metal mold which forms the entire outside surface. A sand core forms the interior water passages. All holes are cored with metal pins, which give a dense, chilled surface quite impervious to leakage. Shapes and sizes are so close to dimension that the only machining necessary is a light cut off the bottom to secure proper volume of combustion chamber.

Special Aircraft Forgings

Interesting and important as these applications are, it is necessary to go to aircraft engines to find all of the peculiar properties of the light alloys required to the last obtainable degree. Here we have engines developing five to ten times the power of an ordinary automobile engine at something like one-fifth the weight per horsepower. They operate almost continuously at 80% or more full throttle, and absolute reliability is the first consideration. Some idea of the importance of the light alloys may be

gained from the fact that if all the materials used in these engines were melted down, aluminum and magnesium would account for three times the volume of all the other materials put together!

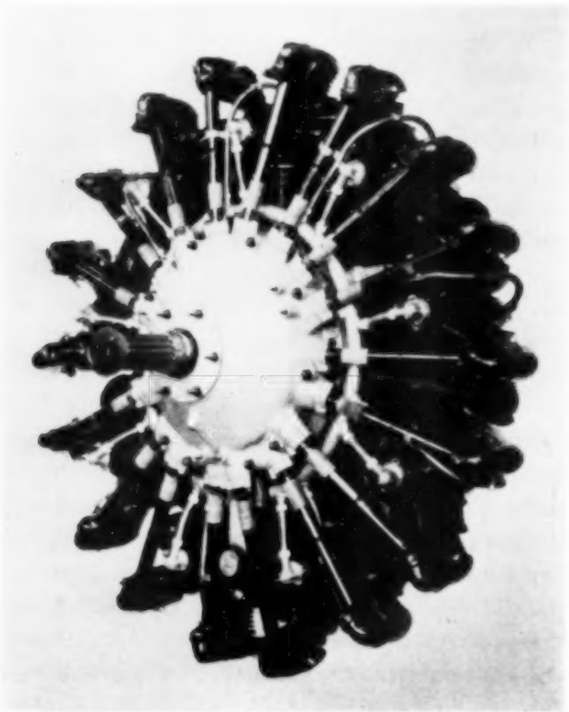
Not only the alloys used but the methods of fabricating them have resulted from exhaustive efforts to obtain the best material in the most desirable form. Uniformity of product is also an imperative necessity, as failures in service must be reduced to an absolute minimum. A wide variety of requirements are encountered.

Crankcases, for instance, must be strong and rigid, capable of withstanding extreme vibratory stresses for long periods of time and at temperatures up to 250° F. The forged alloy 51-S (0.6% Mg, 1.0% Si) meets these requirements and is extensively used. Crankcases for the line engines and "V" type engines, which cannot conveniently be forged, are usually made of the copper-silicon type of alloy.

Nose and rear sections of radial engines are not highly stressed as compared to the crankcase proper, and temperatures encountered are little above normal. Here the dominating factor is an opportunity for saving in weight, and has resulted in the use of magnesium alloys to an increasing extent.

Forged Aluminum Link Rod for Radial Engine Requires Little Machining and No Bushings and Therefore Costs About One-Fifth of Steel Rod

Latest Developments in Radial Engines Produce a Most Compact Design, Using Much Light Alloy. Horsepower has been doubled, weight increased about 25 pounds



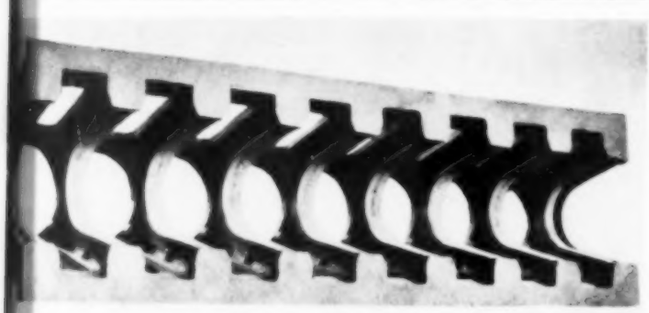
The modern air-cooled cylinder head represents one of the greatest individual advances in aircraft engine construction, both as to material and method of fabrication. The requirements are most exacting. Since the weight of the cylinder heads accounts for half the aluminum in the engine, lightness is extremely desirable. A difference in specific gravity between two aluminum alloys (both acceptable so far as physical properties are concerned) may be as little as 3 or 4%, yet this small difference may amount to as much as 12 or 15 lb. on the total engine, and warrant the use of the lighter material. Most of the heat to be radiated must pass through the cylinder head fins to the air stream, so that high thermal conductivity is also an essential requirement. Operating temperatures may, under certain conditions, rise as high as 700° F., at which temperature the heads must withstand loads of 15 tons applied 20 times per sec. In addition, the material must be practically perfect as to machinability.

To obtain an alloy which will do all these things has required investigations lasting several years, but the result has been accomplished and has made possible the construction and successful operation of engines weighing only slightly more than one pound per developed horsepower.

Equally important is the piston. It must withstand stresses as large as the cylinder head and must operate at an even higher temperature. Lightness is doubly essential here, as the piston

is a rapidly reciprocating part and as such imposes large inertia forces on the bearings. In addition it must operate as a bearing against the cylinder wall and against the wrist pin without scuffing or scoring. A low coefficient of expansion is desirable, as the pistons should be fitted with as little clearance as is possible to prevent tipping in the cylinders with resultant ring wear.

Until two years ago cast aluminum pistons were used almost exclusively in aircraft engines, but the inspection requirements were so rigid and the service so severe that less than half of the castings were accepted. Even then failures were apt to occur in service due to small hidden defects and to lack of ductility in any cast alloy meeting the requirements. To overcome this situation we now have the forged 32-S alloy piston (its nominal composition is silicon 12%, magnesium 1%, aluminum balance). It has a relatively low coefficient of expansion, high thermal conductivity, excellence as a bearing material, and specific gravity even lighter than if it were made of pure aluminum. The remarkable uniformity of such forged pistons is evidenced by a low loss after an inspection which is probably as rigid and exacting as for any part of the engine — for the past three years rejects have only amounted to approximately one piece in a thousand.



Eight-Cylinder Diesel Engine Crank Case, Viewed From Below

Aluminum link rods in small radial engines constitute quite an interesting application. These rods are attached to a master rod which operates on the single throw crankshaft. Link rods are usually made of alloy steel, machined all over and fitted with bronze bushings at either end. Ordinarily in from 500 to 1000 hr. wear these bushings are removed and new ones pressed in and reamed to fit the pins. The cost of this operation is as much as that of the whole aluminum rod, which is thrown away after 1500 hr. and replaced with a new one. The rod itself costs only about $\frac{1}{6}$ as much as a steel rod, because there is practically no machining required. This is one of the instances where an aluminum product is actually a good deal cheaper than the corresponding steel one.

Faster Diesel Engines

As I mentioned at the outset, there has been during recent years an increasing number of applications of aluminum alloys to diesel engine construction, of which pistons, cylinder heads and connecting rods are the most common. In instances where weight limitations are imposed, aluminum has also been used extensively in the construction of frames, bed plates, and crankcases — even very large in size.

Diesel engines of either stationary or marine type are almost always operated at very slow speeds (as compared with those we are accustomed to regard as normal in the automobile) — 100 to 250 r.p.m. is quite common. It is well known that the power which can be taken from an internal combustion engine is almost directly proportional to the speed at which it is operated. The reason that these engines cannot be speeded up is because the weight of the large piston and connecting rod imposes such heavy loads on the bearings that their maximum capacity is reached at these relatively low speeds. The obvious way to get around this difficulty is to lighten the reciprocating parts, which are largely responsible for heavy bearing loads, and then speed up the engine to a point where the new reciprocating forces will be no greater than they were previously. This can be and is being done more and more through the use of aluminum pistons and connecting rods. To obtain the same increase in power by increasing the engine size would mean an entirely new engine of greater bulk, which could only be built at large expense and then might well be too great in dimensions to serve its former purpose.

by George B. Waterhouse
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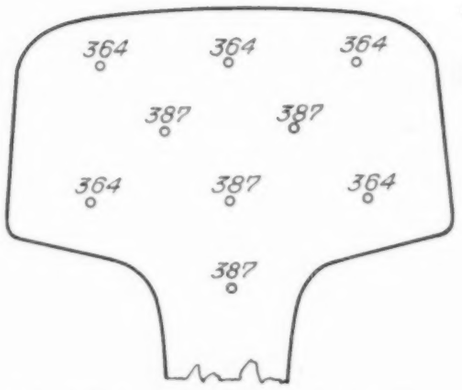
CHROMIUM STEEL RAILS

are harder, tougher, stronger



Brinell Tests Show That Low Carbon Chromium Rail Is Uniformly Hard Throughout After Air Cooling From Finishing Pass

THE STEEL RAIL has been greatly modified in section, length, and composition since first used near Derby in England, about 1861, as was pointed out in an article by T. J. Skillman in METAL PROGRESS, Nov., 1931. That first steel rail was made by the acid bessemer process, and this was the manufacturing method accepted for many years. Almost all the rail steel in this country, however, has been made by the basic open-hearth process for about 20 years, owing to its ability to control the phosphorus in our available iron ores. The general composition is a plain carbon steel fairly high in manganese. A typical chemical specification for rails weighing 121 to 140 lb. per yard is carbon 0.72 to 0.89%, manganese 0.50 to 0.90, phosphorus 0.04 maximum, and silicon 0.15 minimum.

Alloy steels have found only a limited application for rails, partly due to the fact that rails are generally used without heat treatment, being rolled from the ingot, cooled slowly on the hot beds, straightened, drilled, inspected, and shipped to the desired location for placing in track. Most alloy steels need heat treatment to bring out their superior properties, and railroad executives have hesitated to spend the extra money required for the alloy and the heat treatment, not being sure that the increased outlay would be justified.

One type of low alloy steel has been used to a considerable extent and is an exception to the above statement. That is the so-called intermediate manganese steel or medium manganese steel, which is lower in carbon than ordinary rail steel but with higher manganese, the manganese running from 1.30 to 1.60%. It has given evidence of increased resistance to wear under service conditions, especially on curves, and several hundred thousand tons of it are now serving satisfactorily in track.

Some interesting experiments have been going on for almost five years with chromium steel rails and it is now felt that the results represent a real advance in the art.

As early as 1920 C. E. MacQuigg, manager of the Union Carbide and Carbon Research Laboratories, decided to take advantage of those properties of chromium steel that would be of the greatest benefit to rails, namely, the re-

fining of the grain with subsequent toughening and also the penetration of hardening through the section, thus increasing resistance to wear. In order to guard against brittleness the required tensile strength and wear resistance were to be secured by high alloy content and at the same time the necessary toughness and resistance to shock retained by keeping the carbon content low.

EVER since the steel rail has been available the trend has been toward harder, more wear resistant rails. Carbon has been the principal alloying element. Next a little extra silicon and then considerable manganese were added. The latest move is to lower the carbon and get superior hardness and toughness from a chromium alloy.

First a survey of the entire alloy system was made. A considerable number of small heats were made in an electric furnace, one program alone embracing 46 heats with chromium ranging from 1 to 11.2% and carbon from 0.02 to 0.85%, the carbon varying in steps for different groups of chromium. Suitable tests were made on all these heats and the results plotted and worked into graphs and models.

When the theoretical range of the best qualities for rail steel had been established, the next step was to make a number of small open-hearth heats. Out of these heats ten were selected, varying in chromium from 0.82 to 3.20% and in carbon from 0.22 to 0.59%, which were rolled in a commercial way in a cooperating steel mill and their tensile and other properties established after various heat treatments.

The results pointed to an analysis with about 0.30% carbon, 3.00% chromium as being very suitable for further work. Arrangements were therefore made to have a large open hearth heat of this steel made and rolled into rails; this was done October, 1929. The heat was poured into 14 ingots, 25x30 in. in section, each ingot heavy enough to make seven 130-lb. per yard rails after the proper top and bottom discard. The rails were of a section 6¾ in. high, much used for main lines, approved by the American Railway Engineering Association and known as the "130-lb. R.E. section."

Ladle analysis of the heat was carbon 0.25%, manganese 0.69%, phosphorus 0.013%, sulphur 0.020%, silicon 0.25%, and chromium 2.89%. This is very, very different from the usual composition of rail steel as given at the start of this article. It is interesting to see the results of the usual acceptance tests made at the rail mill and compare them with those for ordinary carbon steel rails.

The standard test for rails is the drop test, carried out by placing a piece of rail on supports, with the head up; a heavy weight is raised between guides and falls freely on the rail. Three short pieces of rail are tested from each heat of steel, one each from the top of the second, middle and last full ingot poured. All three test pieces must stand the drop test without breaking for all the rails from the heat to be accepted.

For the 130-lb. R.E. section, the tup is specified to weigh 1 ton; it is to fall freely 22 ft. and strike a 6-ft. length of rail resting on supports 4 ft. apart. Results of this standard drop test on the chromium steel heat showed that the rails were acceptable, as given in the first three lines of the table below.

Each piece stood the blow without breaking, the deflection from the straight being 0.70, 0.70 and 0.75 in. respectively. The elongation figures need some explanation: Before the test each specimen is marked on the center line of the base with gage marks 1 in. apart for 3 in. each side of the middle of the specimen. These distances are measured carefully after the test and the elongation determined in hundredths of an inch. This is a measure of the ductility of the metal.

Another sample rail was taken from the middle ingot and tested to destruction, being

Drop Tests on Chromium Steel Rails

Ingot No.	Blow No.	Deflection Inches	Elongation Over Six Inches	Total
2A	1	0.70	2 3 3 3 2 2	15
8A	1	0.70	2 2 3 3 4 3	17
14A	1	0.75	3 4 4 3 2 1	17
8A	1	0.60	2 3 3 3 2 2	15
	2	1.10	4 5 6 5 5 4	29
	3	1.50	5 7 8 9 7 5	41
	4	2.00	7 9 10 10 8 5	49
	5	2.40	9 11 11 11 9 7	58
	6	2.80	10 12 12 12 10 7	63

Drop Tests on Carbon and Medium Manganese Rails

Heat	Analysis					Blow No.	Deflection Inches	Elongation Over Six Inches						Total
	C	Mn	P	S	Si									
1	0.82	0.78	0.033	0.026	0.25	1	0.75							
						5	Broke	8	8	7	6	4	3	36
2	0.74	0.70	0.027	0.022	0.24	1	0.80							
						6	Broke	7	9	11	10	8	7	52
3	0.72	0.72	0.031	0.036	0.26	1	0.85							
						5	Broke	8	12	11	9	7	6	53
4	0.80	0.79	0.031	0.027	0.35	1	0.75							
						4	Broke	7	8	9	10	8	7	49
5	0.78	0.73	0.029	0.028	0.28	1	0.75							
						6	Broke	8	9	10	11	9	7	54
6	0.77	0.72	0.034	0.034	0.29	1	0.75							
						5	Broke	8	10	11	8	7	7	51
7	0.82	0.71	0.024	0.032	0.24	1	0.80							
						4	Broke	11	9	8	6	5	3	42
8	0.80	0.76	0.030	0.034	0.29	1	0.75							
						4	Broke	3	4	6	8	8	8	37
Medium Manganese Rails, Tested to Destruction														
A	0.61	1.37	0.022	0.035	0.22	1	0.85							
						2	1.50							
						5	Intact	7	9	11	12	10	9	58
B	0.63	1.37	0.023	0.040	0.21	1	0.80							
						2	1.50							
						5	Broke	6	8	10	10	9	7	50
C	0.63	1.57	0.021	0.044	0.26	1	0.80							
						2	1.45							
						4	Broke	5	7	9	8	7	6	42
D	0.59	1.30	0.022	0.045	0.21	1	0.85							
						2	1.50							
						5	Intact	7	9	11	12	10	9	58
E	0.64	1.45	0.022	0.053	0.21	1	0.80							
						2	1.40							
						5	Broke	7	8	10	9	7	5	46
F	0.64	1.40	0.032	0.039	0.23	1	0.85							
						2	1.50							
						6	Broke	7	9	12	11	9	8	56
G	0.64	1.50	0.023	0.028	0.24	1	0.80							
						2	1.40							
						6	Broke	7	8	9	9	7	7	47

measured after each blow of the tup. The results are also given in the table on page 33. All these drop tests were carried out on pieces cut at the hot saw in the rail mill in the usual way and cooled in air.

In order to be able to make a proper comparison, typical results of drop tests on ordinary rails of this same section are given in the table on this page, as well as on medium manganese steel rails, rolled at about the same time. The rails are the same 130-lb. R.E. section and were tested under standard conditions.

It should be noted that the first eight heats of carbon steel run on the high side of the carbon specifications and so are stiffer than the general run of carbon steel rails. Notwithstanding this, they are not as stiff as the chromium rail steel, as shown by the deflection after the first blow. Brinell hardness of similar carbon rail steel shows values over the cross-section of the head varying from about 235 to 245, far below the representative values shown by the special chromium rail steel, which are given in the sketch at the head of this article.

The second portion of the table alongside gives drop tests on some medium manganese steel rails. The latter are not as stiff as the chromium steel rails, which shows that the latter possess ample strength as girders to carry the train from one crosstie to the next. Brinell hardness of typical medium manganese rails varies from only 260 to 280.

Emphasis has been placed on these drop tests because it is a test for rails that has been used for inspection purposes for many years, and gives a valuable indication of the service which may be expected. The combination of stiffness and ductility possessed by these special rails was very promising, and the high Brinell hardness was surprising and indicated that the rails would have good resistance to wear.

Some samples of the chromium steel rails were furnished one of the railroads, and the laboratory cut tensile test pieces from definite locations. Results are as shown at the top of the next page. In comparison the following figures are representative of ordinary carbon steel rails (specification 0.62 to 0.75% carbon): Yield point 64,150, ultimate 125,130 lb. per sq.in., elongation 14.0% in 2 in., reduction of area 19.1%. These are averages of 54 tests made from the center of half the head.

Following these splendid results shown by the various physical tests, arrangements were made to place rails in track and observe their behavior under service conditions, because no laboratory test has yet been devised that will anticipate actual service. In November, 1929, 20 of the rails were laid on a 3° curve on the main track of the Boston and Maine Railroad, at Lincoln, Mass. Ten of the rails were laid on the high side and ten on the low side of the

curve. At the same time medium manganese steel rails were laid at each end of the special rails, so that they could be observed together.

The rails have been frequently inspected and careful profiles of the heads have been taken at intervals. The special chromium rails are standing up well. They show very little wear and are noticeably better than the others, as can be clearly seen by the close-up of a joint. This view was taken at Lincoln after three years' service; the superiority of the chromium steel to the medium manganese steel both in wear and in batter is quite apparent.

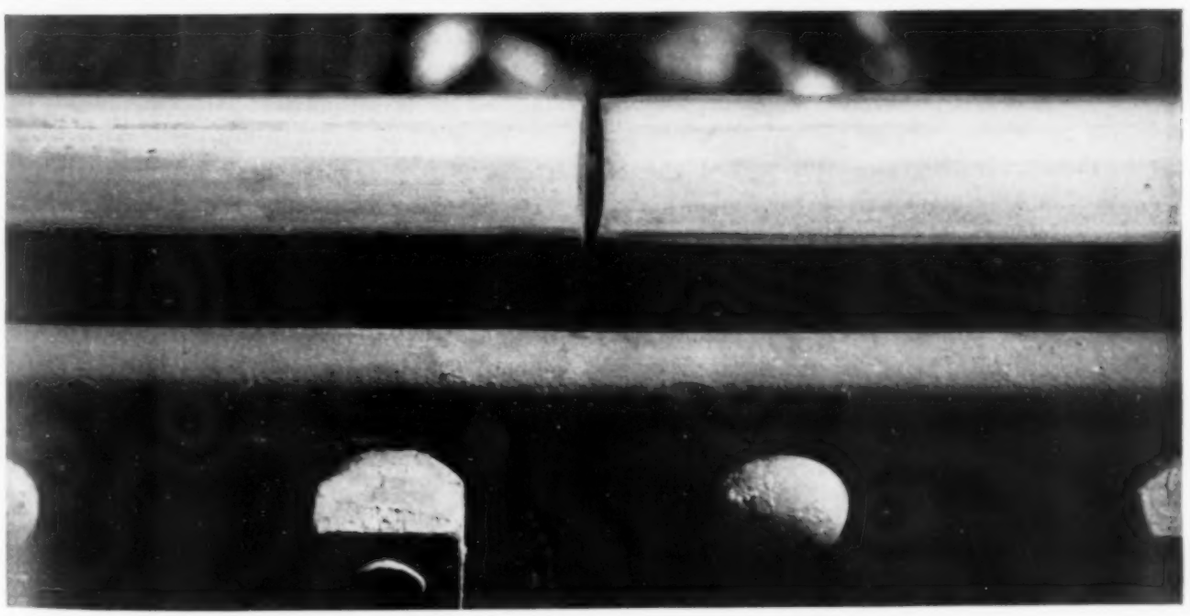
Actual metal abraded from the head after about 39 million tons of traffic had passed in something over four years is as follows: From the medium manganese rail, 0.165 sq.in. from the high rail, 0.125 sq.in. from the low rail; from the chromium steel, 0.090 sq.in. from the high rail, 0.067 sq.in. from the low rail.

A further test is being made on this same railroad on a 9° curve at Hoosick Falls, N. Y. Similar tests are being made by the New York, New Haven and Hartford Railroad, with similar results, where the rails have been in service for three years. Frogs have been made from these special rails without special difficulty in machining, and installed; they are giving satisfactory results. One of these frogs is being compared with a 12% manganese steel frog in similar service, and so far seems to be standing up equally well.

Tensile Strength of Alloy Rail

Location	Yield Point	Ultimate Strength	Elongation in 2 In.	Reduction of Area	Izod Impact
Outside, head	112,800	179,350	14.5	35.7	12.0
Middle, head	111,350	178,250	13.0	26.1	10.4
Outside, base	109,750	179,000	15.0	33.1	15.5
Inside, base	106,700	178,800	15.0	32.1	17.0

Results of actual service in track, therefore, confirm the results of the drop tests and other physical tests and show that chromium rail steel gives excellent results and is considerably superior to the rail steel in use at present. The suggested composition is carbon 0.25 to 0.32%, manganese 0.50 to 0.75%, phosphorus 0.04% maximum, silicon 0.25 to 0.40%, and chromium 2.80 to 3.20%. This has been chosen because rails of this composition do not require heat treatment, but acquire the proper physical characteristics by cooling on the hot bed of the rail mill. This is the same way that ordinary carbon steel and medium manganese steel rails are cooled.



Looking Down on Rail Joint; Chromium Steel at Left, Medium Manganese Steel at Right. Three years' main-line traffic has battered and worn the former hardly at all

by W. E. Blewett, Jr.
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Newport News Shipbuilding & Dry Dock Co.
Newport News, Va.

STRONG NEW METALS

for shipbuilders

SHIPS ARE OLD. BUT THE IRON SHIP dates back only to 1819, when the Vulcan, a small iron gig rowed by six oars, was built on the River Tyne. It was not until 1876 that a small steel paddler for river service in Burma was built. Adoption of steel was retarded by conservatism, reluctance to admit of betterment until virtually compelled to do so, and difficulty in obtaining the material.

Only since the eighties, therefore, has mild steel been generally used for the structure of ships of all kinds. It has proved so successful in these years that we cannot be blamed for using it as a standard of comparison for any new material now proposed for consideration. The reason the present-day ship owner, architect, and builder is interested in anything else is that we now desire to construct ships which will have more speed and more carrying and earning capacity per ton of structure than ever before.

The same is true of machinery. We are using higher pressures and superheat, and our turbines, boilers, and auxiliaries have to take care of this change. The modern ship also has an extensive refrigeration system, requiring materials until recently unknown to the shipbuilder. Furthermore, the quicker turn-around demanded by steamship companies requires that freight handling facilities be bettered with respect not only to time but also to capacities.

Of all these matters, the steel going into the hull is fundamental, so this article will give some recent tests made under the writer's direction on several steels recommended as superior for the ship's structure. Many factors must be considered in a fair appraisal — weight, strength, corrosion resistance, cost, workability, coefficient of expansion, and (in some instances) general appearance.

Weight and strength are perhaps the most important and are the basis of all the recent arguments for high tensile steels. Steel in a ship is put to one of the severest tests — the continued reversal of stresses. There is also the uncertainty of not knowing the exact loads to be carried by any part of the structure. In other words, figuring steels for strength in a ship is a different task from figuring stresses in a bridge truss. Weights, also, have to be carefully investigated to guard against tendency to capsize when the ship is in light condition.

Corrosion is a serious problem, as most of the materials of ship construction are subjected to salt spray, or at best to sea air. Hulls are frequently exposed to acid conditions in our rivers or harbors, as well as destructive bilge waters, oils, and coals. We rely on paints of

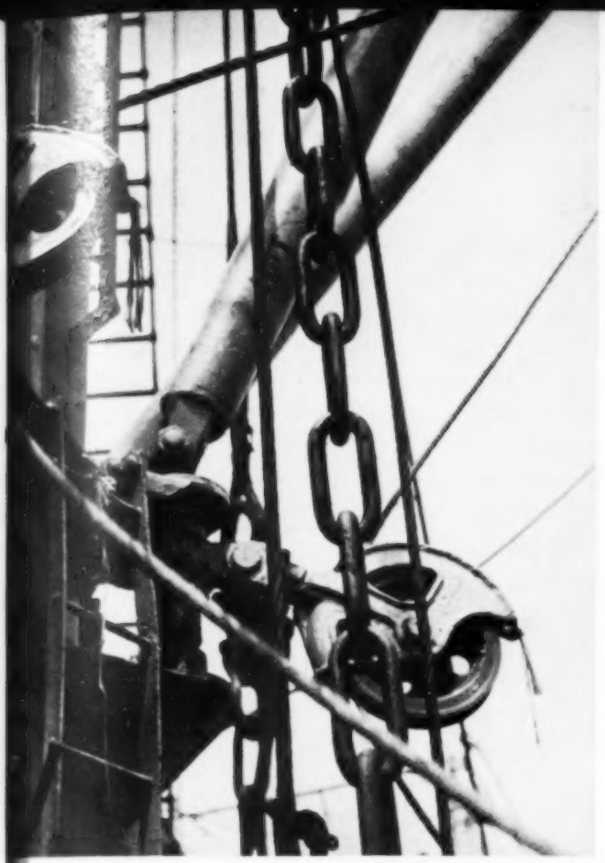

Photo by Irving Browning

various compositions for protection inside and out, but paint is uncertain, as the film is easily and frequently destroyed. Corrosion, particularly in engine room piping, may also be caused by stray currents or galvanic action between different materials, but I am inclined to believe the latter is erroneously blamed when no other cause can readily be found.

Steels in ship work must be readily shaped, sheared, punched, and otherwise fabricated, and the ease with which they can be worked is important in that it affects not only the cost of the ship but also her lines. It is advantageous to be able to shape the steels cold, as hot work is always expensive.

Weldability is very important. Welding is an efficient means of connecting steel members, since it avoids eccentric connections and saves weight. However, the heat of welding is detrimental to some steels, and this limits their use. The amount of welding in ship construction has increased very rapidly in recent years; eight years ago we were using about half a pound of welding wire per ton of steel, while now the ratio is 7 lb. — approximately 14 times as much.

Expansion of the materials under temperature change has to be most carefully watched, particularly those going into the engine room. The hull of some ships is also subjected to severe temperature changes, as, for example, when bunkering with heavy fuel oil which is heated before it is pumped.

High Tensile Steels

Let us now consider how some of these considerations apply to high tensile steels, the most important materials used aboard, and beyond doubt the material most widely discussed. They are not exactly new, however, for a 1.10% silicon steel was used as early as 1907 in the hulls of the Lusitania and Mauretania.

Steels offered to shipbuilders at present may be divided into two general classes: (1) Those obtaining high elastic properties through the use of alloying elements, such as carbon, vanadium, manganese, silicon, and nickel; and (2) those in which the properties are obtained either by tempering or normalizing, or more likely a controlled temperature at the conclusion of the rolling, and a controlled cooling. Of these two classes, the alloyed steel is perhaps the most important and the one from which we may expect to obtain the best results, although as a rule they are more expensive.

From among the numerous possibilities, the Newport News Shipbuilding & Dry Dock Co. has recently investigated six "high elastic" steels, and some of the acquired data are presented in the table on the next page. As a datum for comparison, corresponding figures for mild structural steel are included. Test specimens were cut from plates 36x72x¾ in. in size, supposedly rolled in commercial production. All properties quoted are the average of numerous tests. Tensile tests were pulled in the direction of rolling, although tests cut across the plate at right angles gave close checks.

I do not consider the results of any one series of tests conclusive; in choosing a steel for service it is necessary that numerous investigations be made of commercial steels. Various rollings of the same nominal composition often give diversified results, and the final answer can only be obtained after practical application.

As an indication of how a single series of tests on a limited amount of material may go wrong, we may question the value found by us for the proportional limit of the "silicon structural steel" (al-

though the silicon in this steel is not much above normal for a killed steel). It was recorded as 18% less than mild steel. This certainly does not represent what may be expected, for tests made by the Port of New York Authority on thousands of tons of standard and special steel furnished for the large bridges recently completed in that region (as well as tests on model columns) show that the proportional limit and the "Johnson elastic limit" of the silicon steel are only a little short of the corresponding values of carbon-manganese steel.

The table below also gives figures for such relationships as the proportional limit to the ultimate strength, which are useful in appraising the merit of the steel.

In order to determine the workability of the steels, a hydraulic press was fitted with a 1-in. punch and the pressures required were noted and converted into lb. per sq.in. of area sheared. Although they cannot be construed as ultimate shearing strengths, these figures do form a basis for comparison. The mild structural steel was easiest to punch (47,500 lb. per sq.in.) and the vanadium steel the hardest (68,500). The rest were grouped about midway, and in order of soft to hard ranged as follows: Martinel (54,000), nickel steel (55,000), silicon (57,000), copper-bearing silicon steel (58,500), and Navy high tensile (60,300). This is approximately the same ranking as to Brinell hardness, with the exception of the nickel steel, which appears to punch easily although it is fairly hard.

The plates were also joggled, sheared, and flanged, and although no loads were measured, it was apparent that specimens could be worked satisfactorily. However, the probabilities are that more hot working will have to be done with high strength steels than with the common mild structural steel or ship plate.

The effect of welding on the various plates was investigated by subjecting arc welded specimens to tension and bend tests. All plates (even of silicon steel) were both butt and fillet welded without difficulty, using a low carbon fluxed rod. Tension and bend tests were made on specimens 1 in. wide by the plate thickness, welded into a 45° single V butt, the excess weld metal being machined off flush with the plate. Results are given in the table at the bottom of the right-hand page.

We found that the strength of the weld metal remains fairly constant with an average

Properties of Structural Steel

		U.S. Navy High Tensile Steel	Low Carbon Mn-V Steel	Structural Silicon Steel		Martinel Steel	High Tensile Nickel Ship Steel	Mild Structural Steel
					Copper Bearing			
Chemical composition	Carbon	0.31	0.14	0.38	0.33	0.25	0.21	0.19
	Manganese	0.88	1.42	0.80	0.70	0.66	0.82	0.85
	Silicon	0.28	0.20	0.20	0.30	0.14	0.24	0.11
	Phosphorus	0.031	0.019	0.022	0.026	0.042	0.042	0.027
	Sulphur	0.027	0.017	0.034	0.028	0.043	0.022	0.031
	Other significant elements		0.18V		0.24Cu		2.7Ni	
Average physical properties	Proportional limit	43,100	59,500	25,700?	43,700	31,200	36,200	31,500
	Yield point	45,750	72,300	45,350	48,150	40,450	54,000	37,850
	Ultimate strength	83,300	99,950	88,750	79,650	68,650	83,500	62,100
	Elongation	23.8	18.7	22	25	29	.23	30
	Reduction of area	53	59	42	52	53	53.5	65.5
	Cold bend	180°	180°	180°	180°	180°	180°	180°
	Brinell hardness	149	159	149	143	116	156	100
Yield point ÷ ultimate [%]		54.9	72.3	51.0	60.4	58.9	64.6	60.8
Proportional limit ÷ ultimate [%]		52.0	60.0	29.0?	55.0	46.0	43.0	50.0
Proportional limit ÷ yield point [%]		94.0	82.0	57.0?	91.0	77.0	67.0	83.0
Yield point minus proportional limit		2,650	12,800	19,650?	4,450	9,250	17,800	6,550
Ultimate minus proportional limit		40,200	40,450	63,050?	35,950	37,450	47,300	30,600
% improvement over mild structural steel	of ultimate	34.0	61.0	43.0	28.3	10.5	34.5	
	of proportional limit	38.0	90.0	-18.0?	40.0	0.0	16.0	

of about 67,000 lb. per sq.in. This is what might be expected when the specimens are machined so they will break at the welded section; in other words, we were testing the strength of weld metal made with standard fluxed rod. It does show that a good bond was made between the deposited metal and the base metal in the plates.

In order to determine the effect of the heat of the weld on the various plates, a specimen of each steel was fillet welded and the weld metal then machined off flush with the plate. Examination of etched cross-sections at such regions did not show any marked effect in the base metal, due to the penetration of heat, except in the case of the low carbon manganese-vanadium steel, which showed a concentric banded macrostructure in a region just below the weld.

Trend toward larger and larger ocean liners has reopened consideration of high tensile steels for hull construction. Mr. Blewett presents the results of a comparative study of several such steels — also some notes on other metals used for main frame, power, plumbing and decoration.

For welding the low carbon steels are preferable, since they avoid a severe grain growth below the line of fusion. In the higher carbon steels studied (the Navy steel and the two silicon steels) there is a sharp transition along this line, and the base metal immediately below and adjacent to the line develops a coarse, overheated structure that should diminish the ductility of the weld.

No tests on the endurance limit were made, for I am rather dubious as to how much value can be attached to fatigue figures, as the surfacing of the test specimen has such an influence on the final results. If the fatigue limits could be determined for a working or practical surface rather than a laboratory finish, they would become an important value for the designer. Corrosion also has much to do with it. Therefore, the best we can do is to assume a permissible fatigue limit in bending of 40% of the tensile strength, and 50% of that figure for the torsional fatigue limit.

There is also the compressive strength of these steels to be considered. In a ship's structure a large majority of the important members are subject to compressive loads. Since the modulus of elasticity of all these steels is the same, it will be necessary for stiffness to maintain the areas of the sections; little will therefore be gained in the use of high elastic steel in struts or compression members.

An analysis of the above figures and tests indicates that any or all of these high elastic steels are adaptable for marine use. All of them can be punched without heavy tool replacement (with the exception perhaps of manganese-vanadium steel, but even this can be handled). However, the expense of working the high elastic steels is going to be greater than working our present mild steels until the quality of our tools and our methods of work-

Effect of Welding on Structural Steels

	U.S. Navy High Tensile Steel	Low Carbon Mn-V Steel	Structural Silicon Steel		Martinel Steel	High Tensile Nickel Ship Steel	Mild Structural Steel
				Copper Bearing			
Tensile strength of original plate	83,300	99,950	88,750	79,650	68,650	83,500	62,100
Tensile strength of single Vee weld, ground flush	69,400	67,250	71,050	68,650	65,750	65,850	69,250
Efficiency of weld (%)	83	67	81	86	96	80	114
Bend to first crack	76°	56°	64°	66°	100°	74°	100°
Tests on Plate From Which a Fillet Weld Was Removed							
Tensile strength of plate under weld	83,300	98,000	89,100	77,850	69,650	83,200	63,100
Change from original figures, %	0	-2.0	+1.5	-2.3	+1.4	-0.2	+1.6
Angle of bend, heated side stretched	180°	145°	65°	180°	180°	165°	180°
Condition after bend	Broken	Broken	Broken	O.K.	O.K.	Broken	O.K.
Angle of bend, heated side compressed	170°	180°	100°	180°	180°	140°	180°
Condition after bend	Cracked	O.K.	Broken	O.K.	O.K.	Cracked	O.K.

ing, both hot and cold, can compensate for the change in the nature of the steel.

In confronting the problem of selecting from the above group the best steel for ship construction, the element of cost would have to be considered. In a vessel of "super-liner" size, which requires approximately 27,000 tons of steel, about 45% of the total would be adaptable to high elastic steel, and any premium would run into a large sum of money.

It seems to me that the structural silicon steel containing 0.24% copper showed up as well, if not better, than any. Copper-bearing steel has often been considered for the superstructure, such as for ventilator cowls and deck houses, but I have not heard of its being extensively used. From our experiments there is apparently nothing to be gained from it in under-water work. It must be used with care because in the presence of an electrolyte, galvanic action is likely at joints with other steels.

A Variety of Forgings

In addition to structural steel, there are many other steels used in the construction of a ship — so many that space will permit mention of but a few.

Large hull forgings such as stern frames, stems and rudders, where fire welds may be necessary, are made of 0.08 to 0.15% carbon steel, with 0.3% to 0.7% manganese. From this material we obtain an elastic limit of between 28,000 and 35,000 lb. per sq.in., with an elongation of 40%. Such forgings meet the physical requirements without any heat treatment.

For case hardened parts and for small hull forgings, such as stanchions, hinges, cleats, or rigging forgings, we use 0.15 to 0.20% carbon with the same amount of manganese; its elastic limit is from 30,000 to 35,000 lb. per sq.in. If normalized, its physical properties can be increased from 5 to 10%.

All heavy engine and hull forgings for the merchant marine, such as propeller line shafts, reduction gear shafts, coupling sleeves, crank pins, and rudder stocks, are made from steel containing 0.20 to 0.30% carbon and 0.4 to 0.7% manganese, usually heat treated to an elastic limit of from 32,000 to 45,000 lb. per sq.in., with 25 to 38% elongation.

For hydraulic work, piston rods and large keys, higher carbon steels are necessary. For large diesel engine forgings, carbon-vanadium steel in the normalized and drawn state will give an elastic limit of 58,000 to 65,000 lb. per sq.in., with an elongation of 24 to 30%.

For propeller line shafts, rotor shafts, and crankshafts, Navy specifications call for nickel steel forgings containing 3.25 to 3.75% nickel and 0.30 to 0.40% carbon, an elastic limit of 50,000 to 65,000 lb. per sq.in. and elongation of 25 to 30%. This nickel steel also has improved impact as well as increased elastic limit and hardness without loss in ductility.

Before the subject of forgings is left, a sentence or two may be said about rivets going in the ship's bottom. Some marine operators prefer iron, others alloy, and still others plain mild steel. All three will corrode and leak, but the rate of corrosion depends more upon the protective coating and the care taken of the ship's bottom than upon the material used. In making a selection the service in which the ship operates should be considered. Proper

Heat Treated Steel, Stainless Steel, and Special Non-Ferrous Alloys Are Required in Increasing Amounts in the Ship's Power Plant, as Steam Pressures and Superheats Are Increased. Many of the old reliable alloys are ruined in short order by the new conditions

Sometimes the Emphasis on Luxury and Spaciousness of Passenger Accommodations Is so Great That the Ship Is "Built Around the Decorations." Sea atmospheres are a powerful incentive to use permanent, non-corrodible and stainless metals

heating and driving of shell rivets are also very important factors.

There are a few locations in ships where high tensile steel castings are desirable, namely, rudder castings and stern frames. On Government work a casting with 85,000 lb. per sq.in. tensile strength, 53,000 yield point, and 23% elongation is used, which properties are obtained by using 1.5% nickel, 0.6% chromium or 3 to 3½% nickel. The former alloy is cheaper in raw material but more difficult to obtain free from shrinkage cracks. These cracks also occur although to a much less extent in the 3% nickel castings. For ordinary hull and machinery castings, an ultimate tensile strength of 60,000 lb. per sq.in. and elongation of 24% are usually required.

High chromium stainless steels are rapidly finding new applications in marine work other than in the power plant, where they have been widely used for turbine blading, valve disks and valve stems. On the first stages of the impulse blading we use stainless steel, on the intermediate stages monel metal, and on the last stages manganese bronze. For the diaphragm in the higher temperature stages we use stainless steel vanes cast into the steel housing, and in the lower temperatures monel metal vanes. Other builders have other ideas.

We have found that stainless steel has a very useful place in galley equipment, as well as for fittings and ornamental work in passenger quarters. It is now being introduced into parts where monel metal was previously used, and we believe it is cheaper, less subject to corrosion by unusual liquids, equally as tarnish resistant, and stronger (which permits the use of lighter gages). However, it is harder to work, which is a big disadvantage, but with succeeding jobs the shop mechanics seem to understand it better. As a non-magnetic austenitic steel it will probably be used extensively in the structure adjacent to the navigating instruments. While I have not heard of a specific use in this respect in merchant vessels, I see no reason why it will not be a very useful metal on the top sides.

Non-ferrous metals take an exceedingly important part in the interior decorations. Window frames, which were previously made of wood, are now made of extruded brass, and I do not think it will be long before they will be made of white non-tarnishable alloys. Toilet fixtures and hardware, which used to be nickel plated, are now chromium plated.

Although stainless steel has not been used extensively in interior decorations aboard ship, I see no reason why it will not in the future replace some of the elaborate woodwork. As is demonstrated by many artists and architects, this steel may be etched or finished variously so that it will accomplish a decorative as well as a structural effect.

Non-Ferrous Alloys

Non-ferrous metals and their alloys, due to their corrosion resistant properties, constitute a very important group of materials, the quantities used in ship construction being surprisingly large. For example, a ship of about 30,000 tons displacement requires approximately 350 tons of non-ferrous metals.

Due to its resistance to corrosion, copper

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and its alloys is perhaps the most extensively used metal for piping, but some unlooked-for phenomena always keep us on the look-out for improved materials. For instance, copper pipe is commonly installed in the sanitary and salt water circulating systems, but severe pitting sometimes occurs after a short period of time. It is usually thought that this is caused by stray electric currents, but the pipe lines on one vessel that I know about were checked and no stray currents found. Electrolytic action between impurities in the pipe has never been proved, as the copper used in the pipe is quite pure. In one severe case the copper was replaced with red brass pipe, which is much more difficult to work, but this did not cure the trouble. We installed genuine wrought iron galvanized pipe in these same systems on more recent ships, and to date we have not received any serious complaints.

Opinions about condenser tubes are also very diversified, and some very extensive scientific investigations have been made on the subject. We put admiralty metal tubes into most of our condensers; it contains 70 to 72% copper, 1.2% tin, 0.06% iron maximum, 0.075% lead maximum, and the remainder zinc. Its principal characteristics are ductility and resistance to corrosion.

We have fitted condensers in some recent ships with "Blackskin Finish" tubes of admiralty metal, having a coating of black cupric oxide on the surface, which serves as a protection against corrosion. However, even this material has given trouble, and in a search for still better materials we are now using an aluminum bronze tube composed of 76% copper, 22% zinc, 2% aluminum. Mr. Worthington in METAL PROGRESS last July has called attention to the advantage of 80 copper 20 nickel tubes for condensers in turbo-driven ships where admiralty tubes fail in a very few years.

In conclusion, it may be remarked that as the services become more severe, the choice of materials becomes more and more complex and the number of options greater. Thus the shipbuilder has to be versed in the latest developments in metals and requirements of the service. Most important of all he has to differentiate between sales propaganda and actual performance of the materials.

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Anaconda seamless tubes offer rigidity of construction, coupled with lightness in weight. They are rust-proof and durable . . . and attractive. And they are more satisfactory and lower in cost than similar parts fabricated from sheet.

If you are one of those alert manufacturers who have investigated the design, production and performance possibilities of tubular shapes, consider also the additional advantages of *seamless, durable, copper-alloy tubes.* We are prepared to supply a large number of stock shapes and sizes . . . and to quote upon and produce tubes to your individual specifications.

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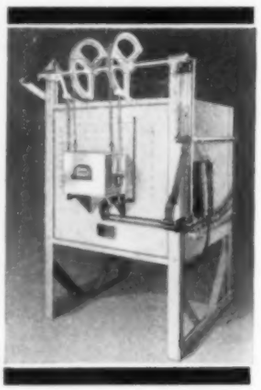

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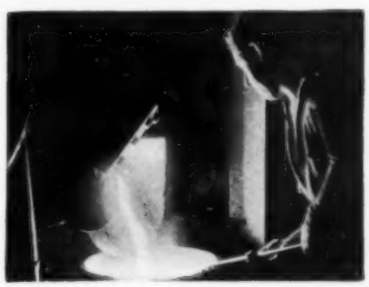

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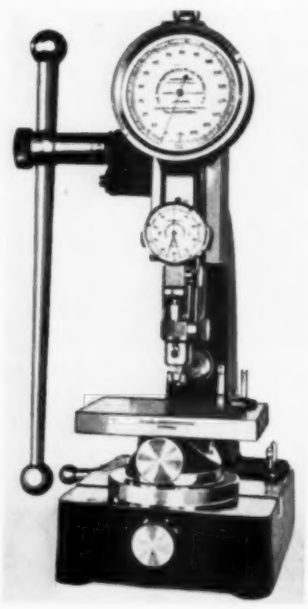

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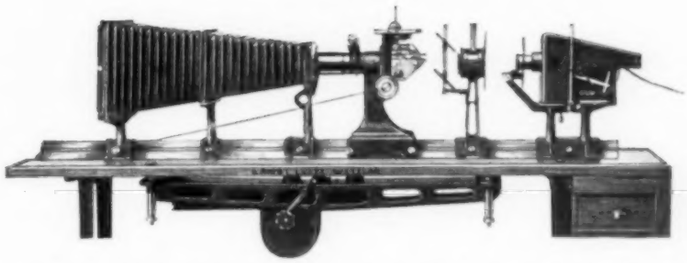

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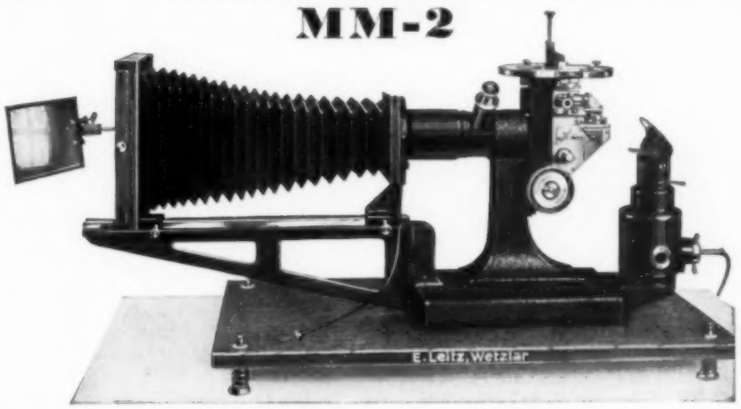

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